National Aeronautics and
Space Administration

VIPER

The Rover Software of the VIPER Mission

Hans Utz

January 25, 2021

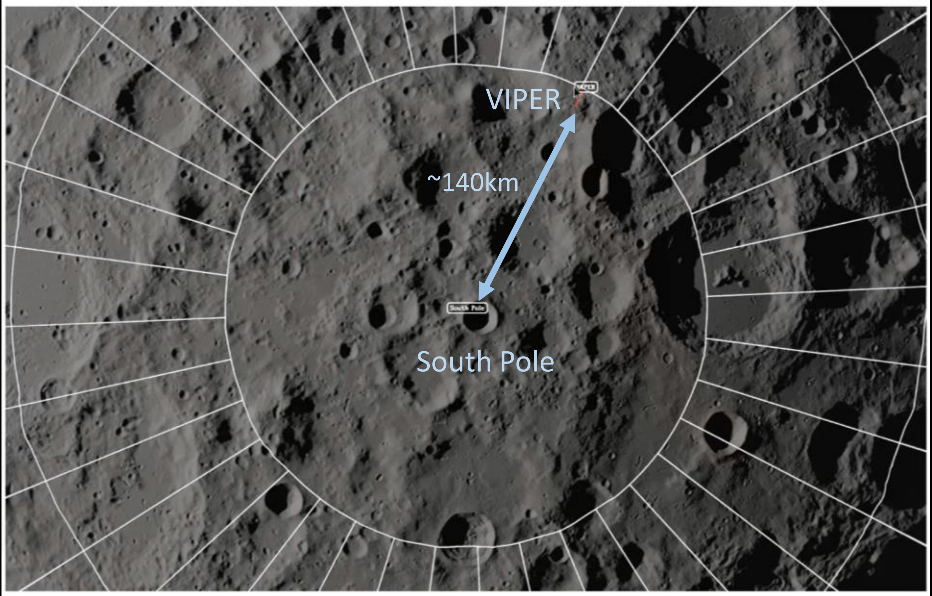
Outline

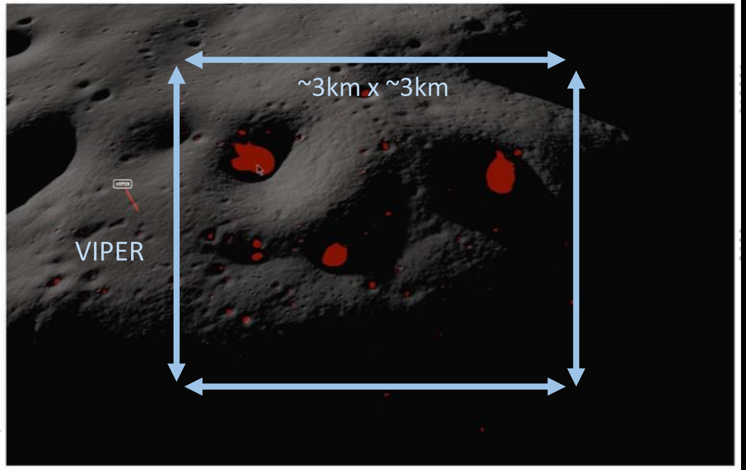
- VIPER Mission
- VIPER Rover Software
    - Rover Flight Software
    - Rover Ground Software
    - Rover Simulations
- Rover Software Development
- Status

VIPER Mission Overview

VIPER: Surface Mission at the Lunar South Pole

- NASA’s VIPER Mission is sending a rover to the south pole of the moon (Nobile region)
- It’s objective is to characterize the surface and subsurface water ice at the lunar south pole in and around permanently shadowed regions (PSR’s)
- The rover is operated in continuous communication from earth
- Only survival functionality during out-of-comms configurations (earth below horizon etc.)
- As the rover is solar powered operations will be carefully aligned with the movement of the sun/shadows over the lunar pole
- The rover survives short polar summer nights and operations in PSR’s on battery power





Screenshots from the VIPER Traverse Planning tool /M. Shirley

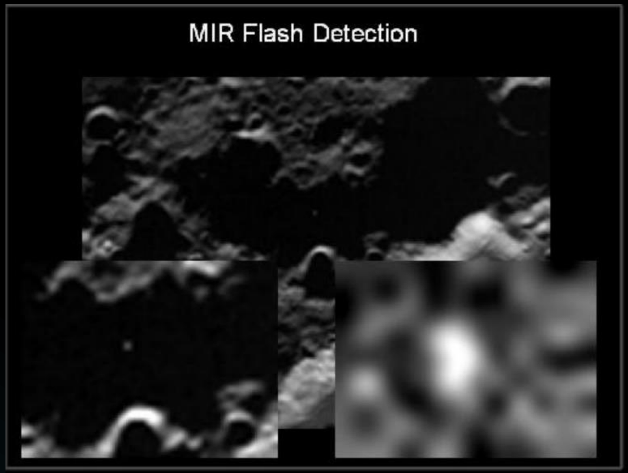
Water at the Lunar Poles

Satellite data

- Clementine probe (1994): Bistatic radar experiment
- Lunar Prospector probe (1998): Neutron spectrometer

LCROSS Lunar impact (Oct 9,2009)

- Impacting an empty rocket stage into the moon
- LCROSS flying through and analyzing ejecta plume



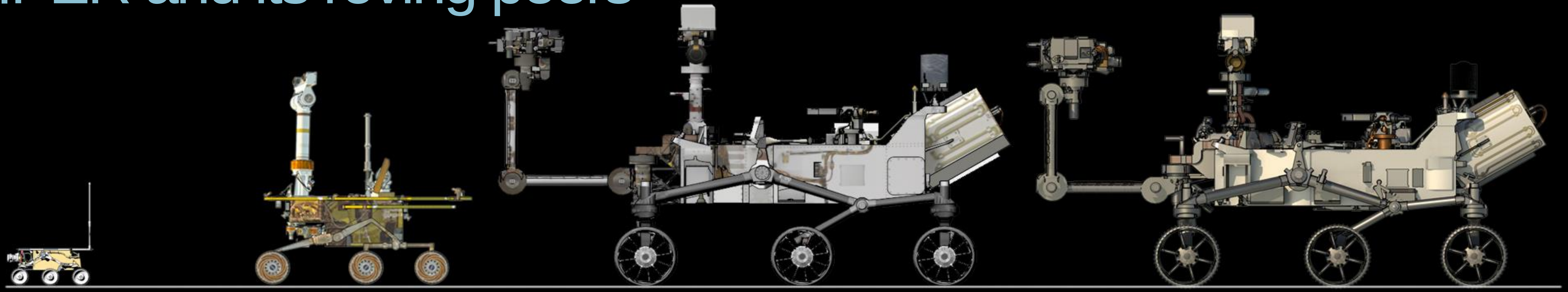
VIPER Mission Parameters

- **Surface Duration: ~1**00 earth days (4 lunar days)
- **Instruments:** Neutron, Near-IR, and Mass Spectrometers; 1m Drill
- **Drill Depth:** 1m (~3ft)
- **# of Subsurface Assays (drill sites):** ~32
- **Dark Survivability:** 50hrs
- **PSR Working Duration (w/drill):** 10hrs
- **Distance Travelled (goal):** ~27km (~17mi)

The VIPER Lunar Rover

aka VIPER Surface Segment

VIPER and its roving peers

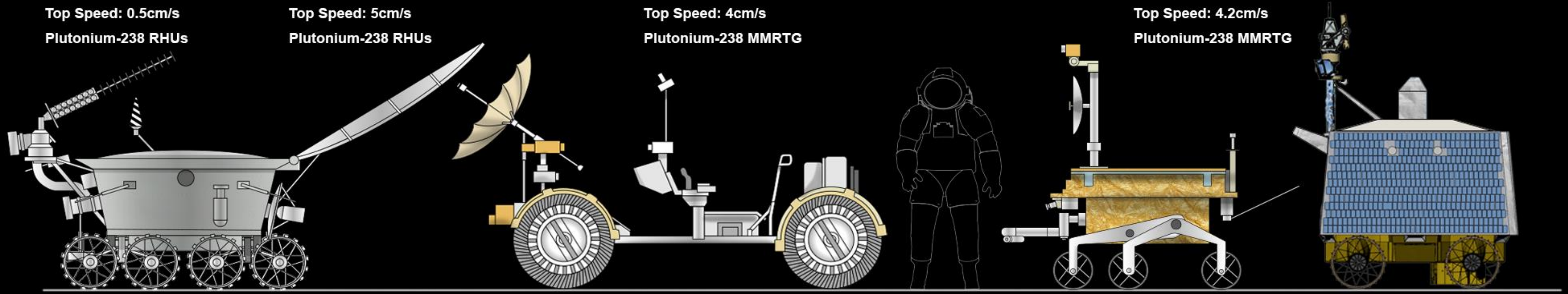


Sojourner (1996)
0.6m x 0.5m x 0.3m
11kg
Top Speed: 0.5cm/s
Plutonium-238 RHUs

Mars Exploration Rover (2004)
1.6m x 2.3m x 1.5m
180kg
Top Speed: 5cm/s
Plutonium-238 RHUs

Mars Science Laboratory (2011)
3.0m x 2.8m x 2.1m
900kg
Top Speed: 4cm/s
Plutonium-238 MMRTG

Mars 2020 Rover (2020)
3.0m x 2.7m x 2.2m
1025kg
Top Speed: 4.2cm/s
Plutonium-238 MMRTG



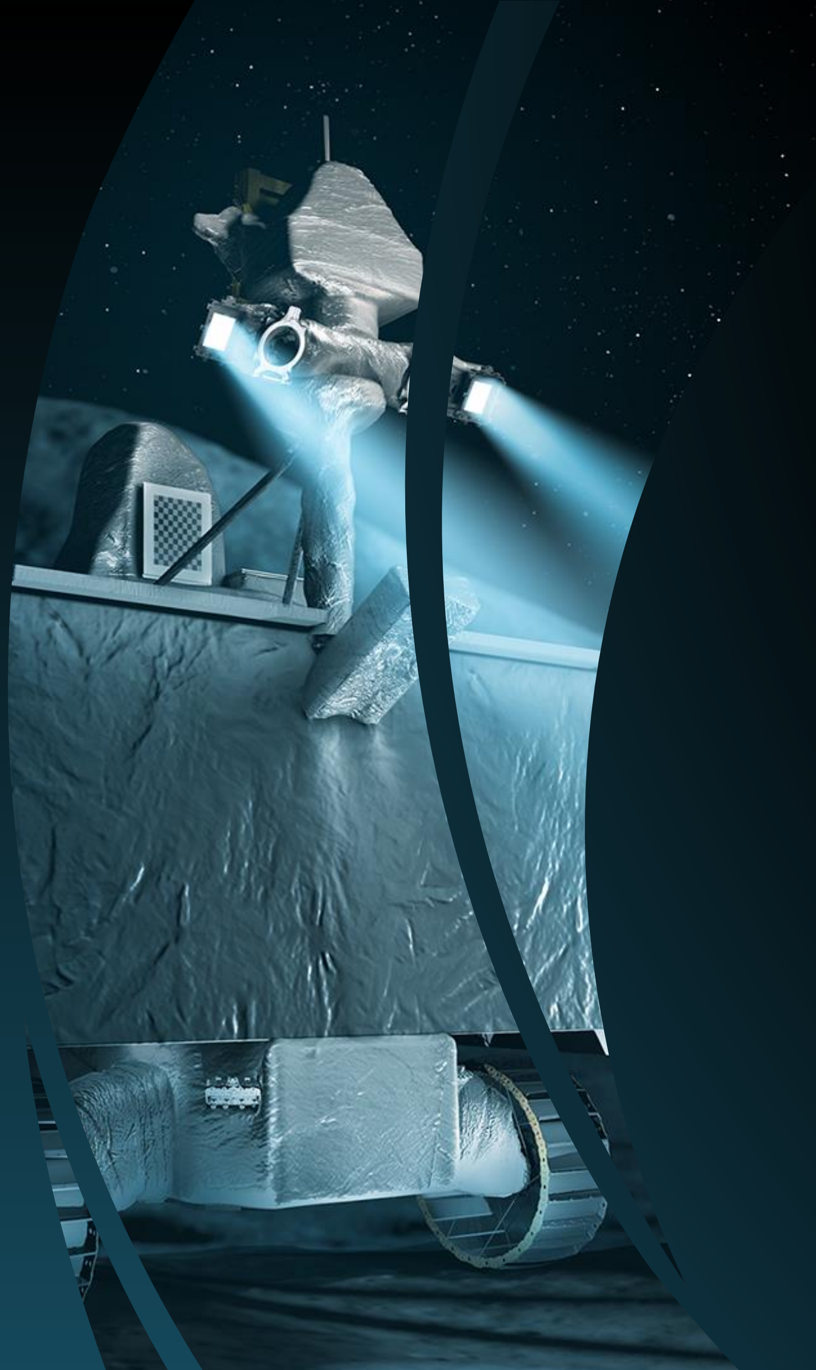
Lunokhod 1 & 2 (1970/1973)
2.3m x 1.6m x 1.5m
840kg
Top Speed: 55cm/s
Polonium-210 heat source

Lunar Roving Vehicle (1971/1972)
3.1m x 1.6m x 1.5m
210kg
Top Speed: 500cm/s
2 silver-zinc 36 volt batteries

1 meter

Yutu (2013/2019)
1.5m x 1.1m x 1.1m
140kg
Top Speed: 5cm/s
Plutonium-238 RHUs

VIPER (2023)
1.5m x 1.5m x 2.0m
430kg
Top Speed: 20cm/s
Electric heaters only



VIPER Rover Parameters

- **Rolling Mass:** ~450kg (992lbs)
- **Communications:** X-band
  - 256kbps (DTE min.) / 2kbps (DFE min.) [1]
  - 6-15[s] round-trip latency / (24h x 14d x 3m)
  - Ground: DSN 34m dishes: Canberra, Goldstone, Madrid
- **Dimensions:** 1.7m x 1.7m x 2.5m (5ft x 5ft x 8ft)
- **Wheel Diameter:** 0.5[m] (20in)
- **Steering:** Explicit steer; adjustable suspension
- **Top Speed:** 20cm/s (0.5MPH)
- **Prospecting Speed:** 10cm/s (0.25MPH)
- **Waypoint Driving:** ~5m (16ft) command distance
- **Camera Look-ahead:** 8m (26ft)
- **Obstacles / Slopes:** 20cm (8in) / 15deg
- **Expected Cold Environment:** ~40K (-390degF)

[1] DTE = Direct-To-Earth / DFE = Direct-From-Earth

VIPER Instrument overview

Neutron Spectrometer System (NSS)

NSS (NASA ARC, Lockheed Martin ATC)

PI: Rick Elphic (NASA ARC)

Prospects for hydrogen-rich materials while roving, mapping the distributions

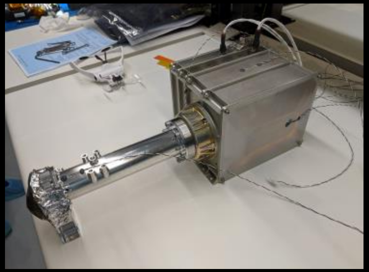
Instrument Type: Two channel neutron spec

Key Measurements: NSS assesses hydrogen and bulk composition in the top meter of regolith, measuring WEH while roving

Operation: On continuously while roving

Specs: 1.9kg, 1.6W, 21x32x7cm (sensor) / 14x18x3cm (Data proc. module)

Mass Spec. Observing Lunar Operations (MSolo)



MSolo (KSC, INFICON)

PI: Janine Captain (NASA KSC)

Prospects for surface volatiles while traversing and during drilling

Instrument Type: Quadrupole mass spectrometer

Key Measurements: Identify low-molecular weight volatiles between 1-100 amu, unit mass resolution to measure isotopes including D/H and $0^{18}/0^{16}$

Operation: Views drill cuttings, volatile analysis while roving and during drill activities

Specs: 6.0kg, 35W, 16x20x46cm

Near InfraRed Volatiles Spec. System (NIRVSS)

NIRVSS (ARC, Brimrose Corporation)

PI: Anthony Colaprete (NASA ARC)

Prospects for surface water “frosts” and evaluates excavated materials

Instrument Type: NIR Point Spectrometer, 4Mpxl Panchromatic Imager w/7 LEDs, 4-ch thermal radiometer

Key Measurements: Volatiles including H_2O, OH, and CO_2 & mineralogy, surface morphology/temps

Operation: On continuously while roving and during drill operations

Specs: 3.6kg, 29.5W, 18x18x9cm (spec) / 20x13x15cm (Obs bracket)

The Regolith and Ice Drill for Exploring New Terrains (TRIDENT) Drill

TRIDENT (Honeybee Robotics)

PI: Kris Zacny (Honeybee)

Excavates lunar regolith to 1-meter and measures forces, displacements and temperatures for regolith bulk properties

Instrument Type: 1-meter hammer drill

Key Measurements: Excavation of subsurface material to 100 cm; Subsurface temperature vs depth; Strength of regolith vs depth

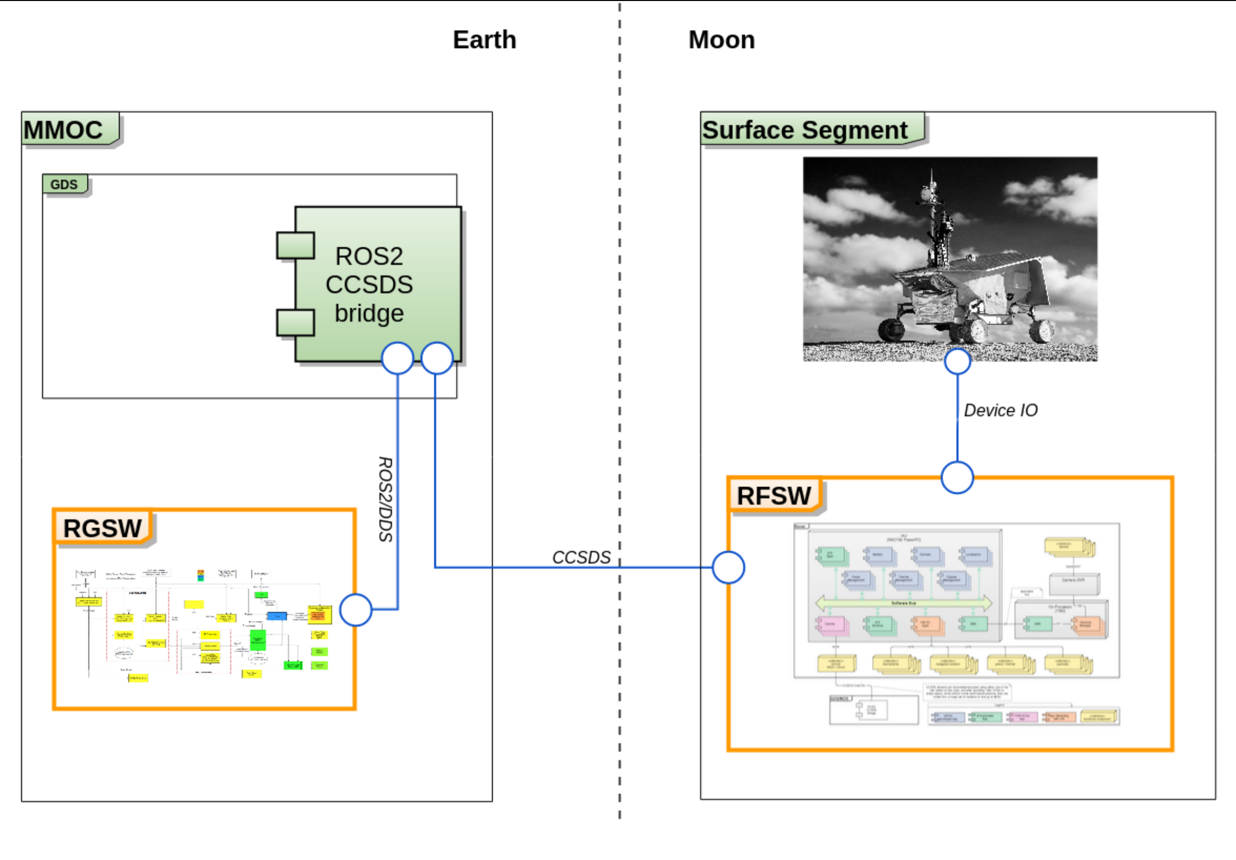
Operation: Subsurface assays to 100 cm in <1 hr, depositing cuttings at surface

Specs: 18kg, 20W/175W (nom/max), 27x22x177cm

Software Architecture

Rover Software split architecture

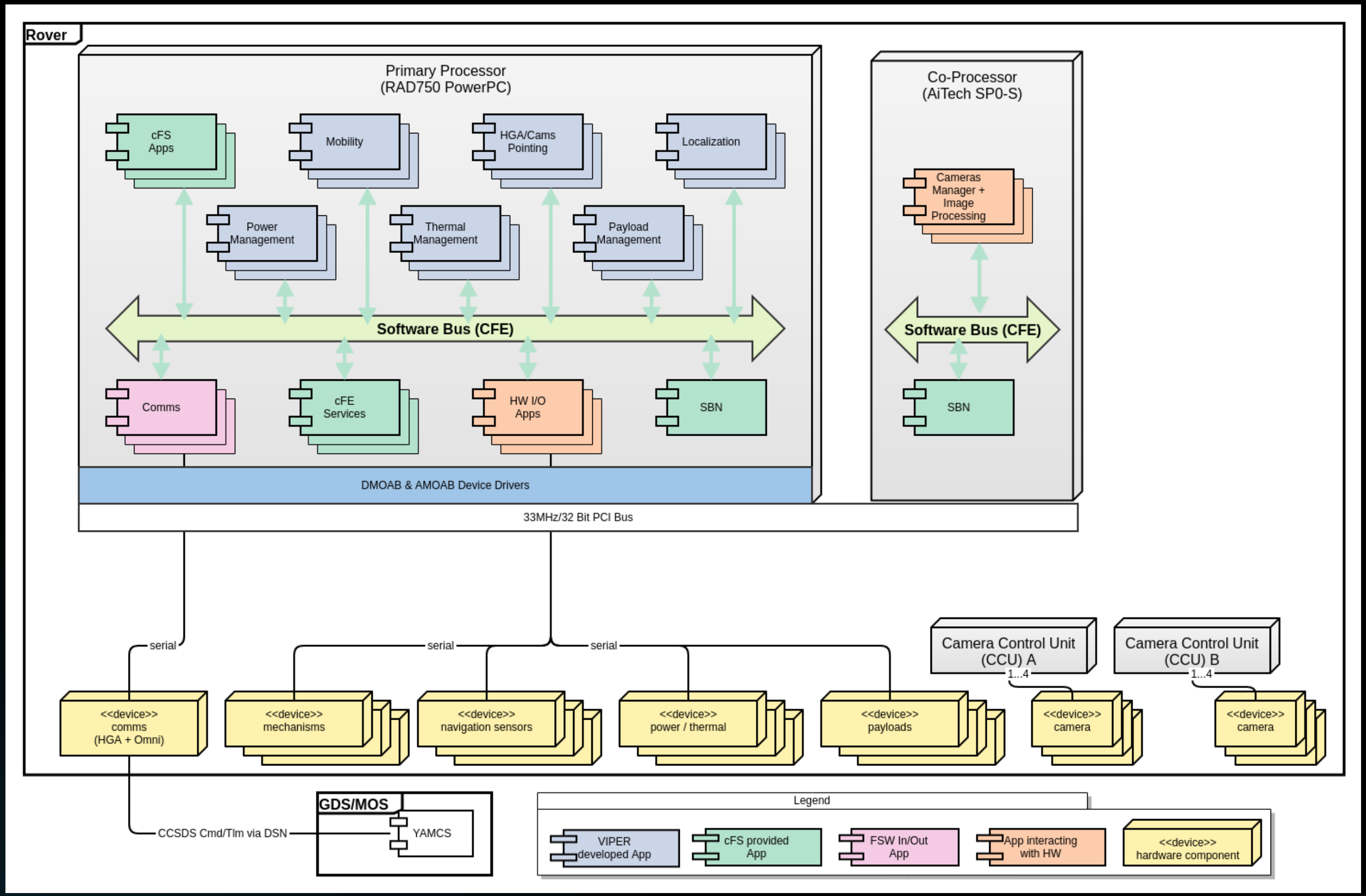
- On-board - Rover Flight Software (RFSW)
  - Flight HW management
  - Operational safety
  - Basic rover surface mobility
- Off-board - Rover Ground Software (RGSW)
  - Deployed on the ground
  - Mobile robotics functions



Rover Flight Software (RFSW)

Rover Flight Software

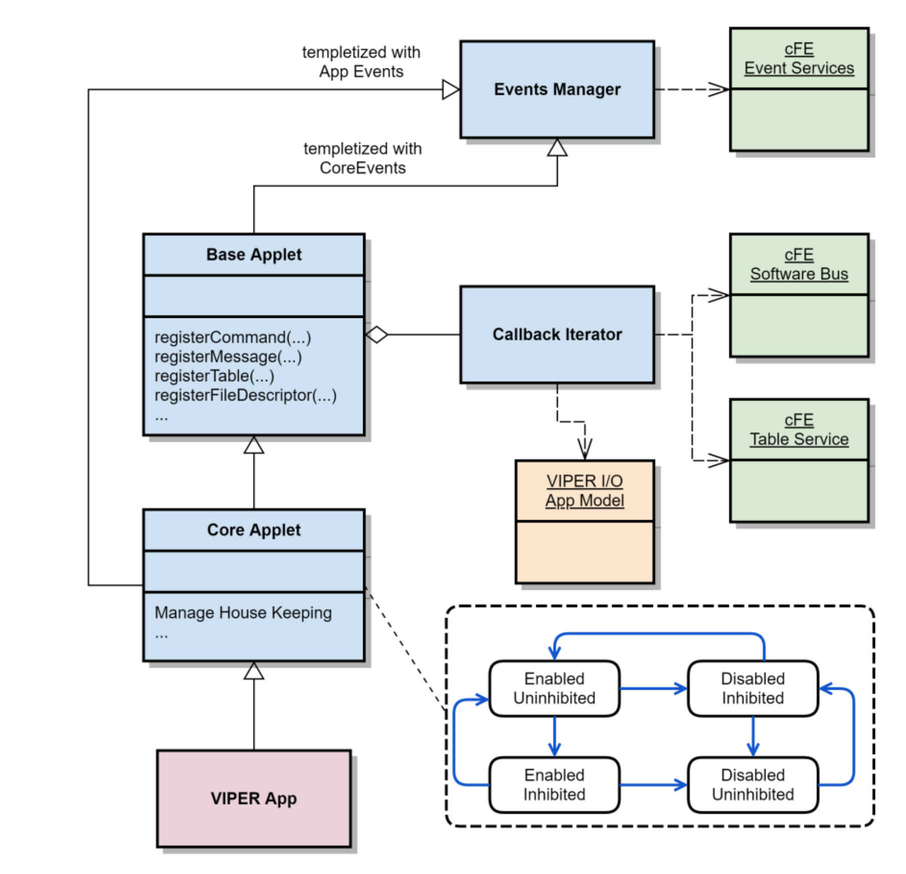
- Based on the NASA cFE/cFS middleware
- Implemented in C++
- Target platform is 2 PPC computers running VxWorks
  - Radiation hard main processor (RAD750, 200MHz, 1GB RAM)
  - Radiation hard co-processor (SP0-S, 1GHz, 1GB RAM)



CoreApplet – cFE/cFS C++ Wrapper

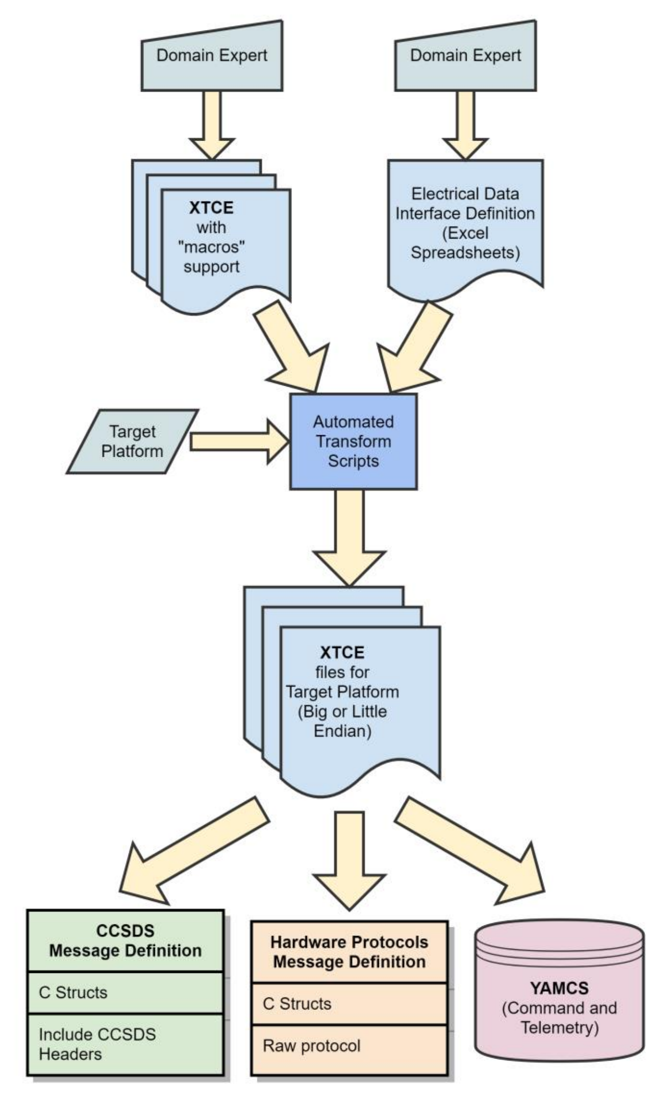
- RFSW is based on NASA's cFE/cFS framework
  - Set of middleware services (cFE services)
  - Set of general purpose applications (cFS apps)

- CoreApplet
  - Small C++ framework (8 classes)
  - Wrapper of cFE services (ES, SB, TBL, EVS)
  - Event-based programming model
    - Function pointer callbacks
    - Strongly typed via C++ templates
    - Multiplexing multiple even sources
      - Software bus messages
      - Table updates
      - Device reads
  - Hooks for common cFS functions
    - Housekeeping telemetry requests
    - cFS app state model: enable/disable
  - IO abstraction for device communication
    - Multiplexing via select()
      Adapted cFE to make SB message queues selectable, too
    - Half sync half async pattern

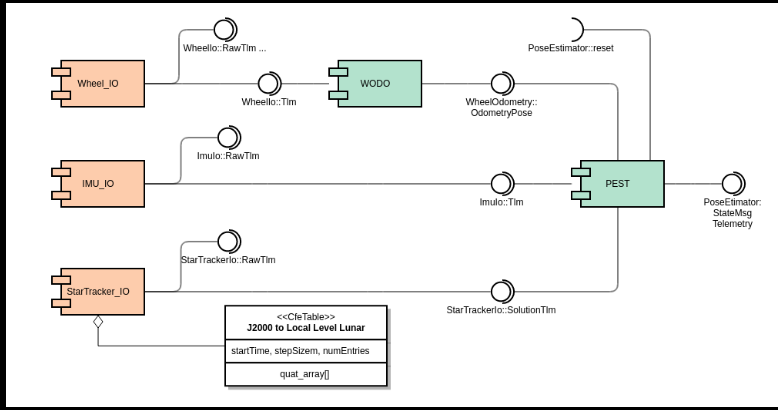


Interface Definitions (XTCE)

- XTCE
  - Interface definition language (IDL) for the YAMCS ground system
  - XML dialect describing types, data structures in complex detail
  - cFE/cFS does not provide it's own IDL
- Used for all interface definitions
  - Ground to RFSW
  - RFSW to hardware devices
  - RSIM using device XTCE for implementing device interfaces
- Single source of interface definition for different services and targets
  - Big endian and little endian targets (PPC & x86 Linux)
  - Filter tables for TelemetryOut (TO) and DataStore (DS) apps
  - Telemetry limit checker (LC) definitions for fault management
  - Binary on-board command sequences (RTS & ATS)



On-board Robotics Functions



Pose estimation (PEST)

- Local position tracking from wheel odometry (WODO)
- Attitude from start tracker & IMU

Kinematics control

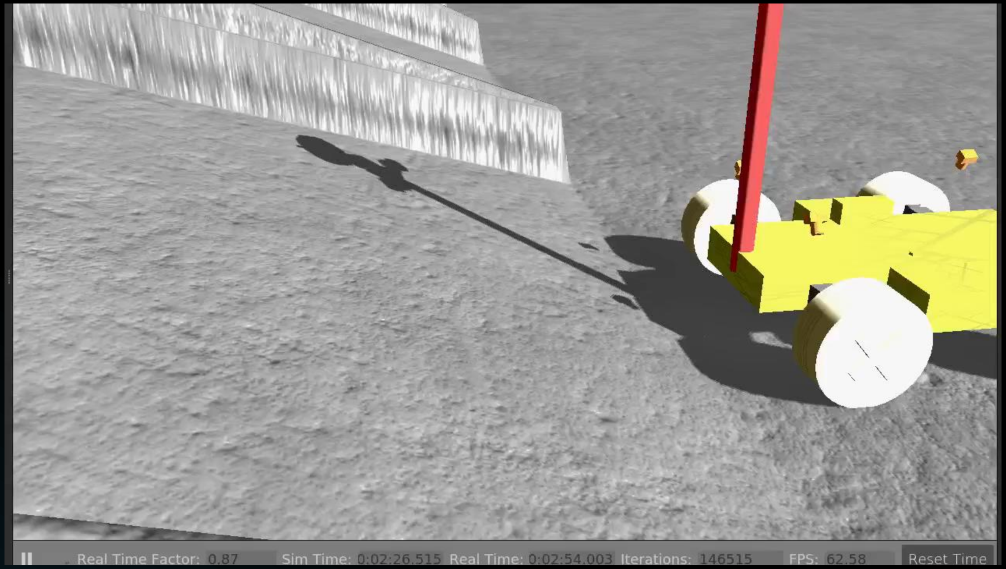
- Driving straight at crab angles
- Point turns
- Stance control
- Active suspension

Waypoint driving

- Driving to relative way point in straight line
- Control loop closed on orientation

Image pre-processing

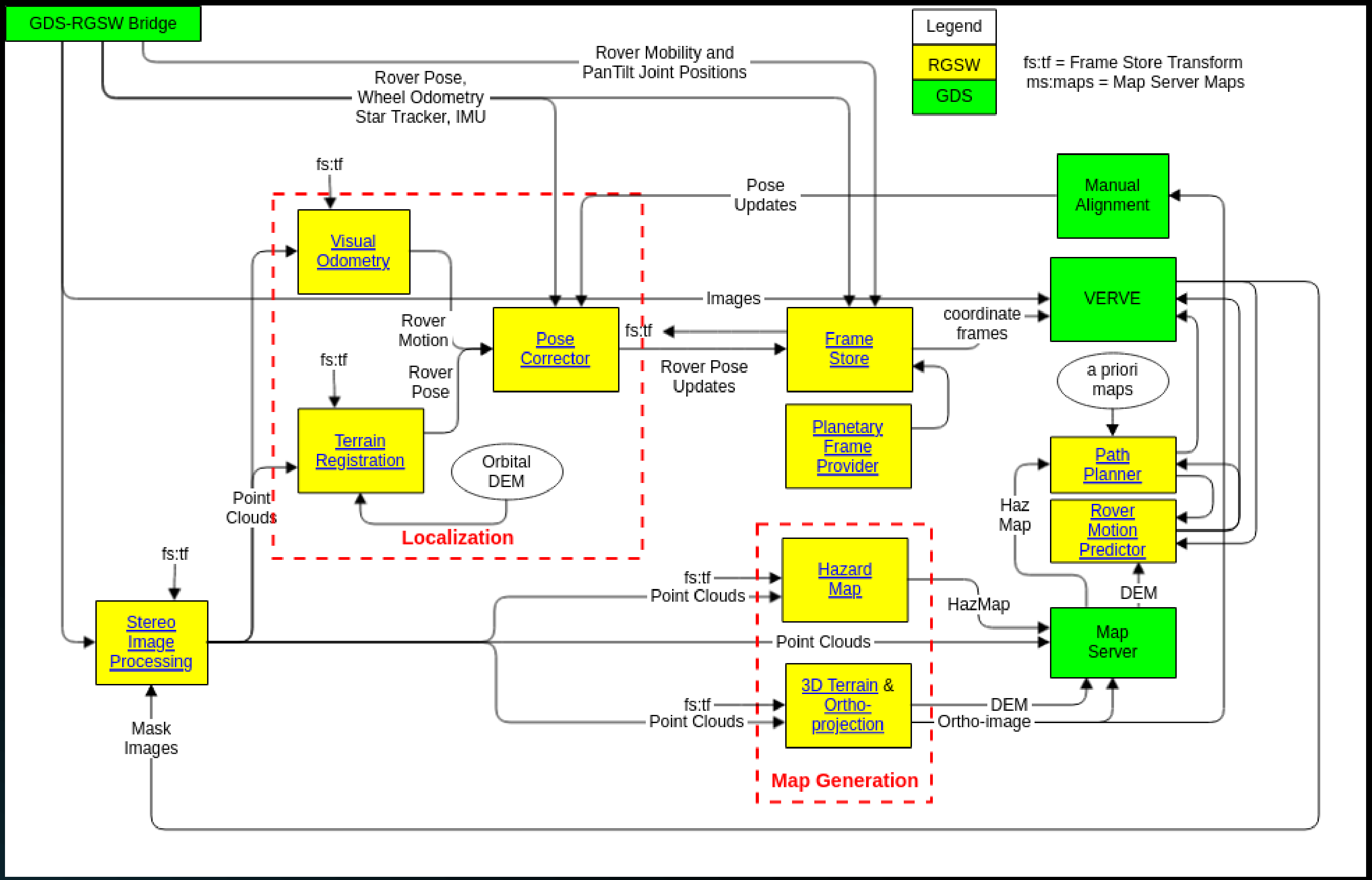
- Bandwidth reduction before downlink
- Lossless & lossy compression techniques
- Requires some stereo (pre-) processing steps to be performed on board



VIPER Rover Ground Software (RGSW)

Rover Ground Software Architecture

- Based on ROS2
- Deployed on the ground
- Linux workstations
- Large eco-system of Open Source robotics software
- Extended with mission specific functions and algorithms



RGSW –
Relative & Global Localization

Stereo image processing

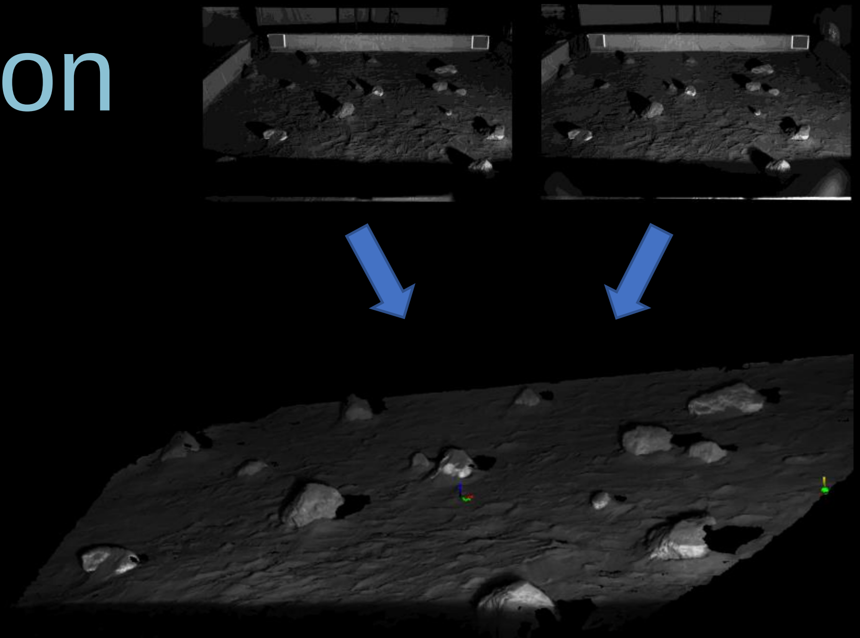
- Generating point clouds from stereo image pairs
- Mesh generation
- Mapping context images onto mesh as texture map

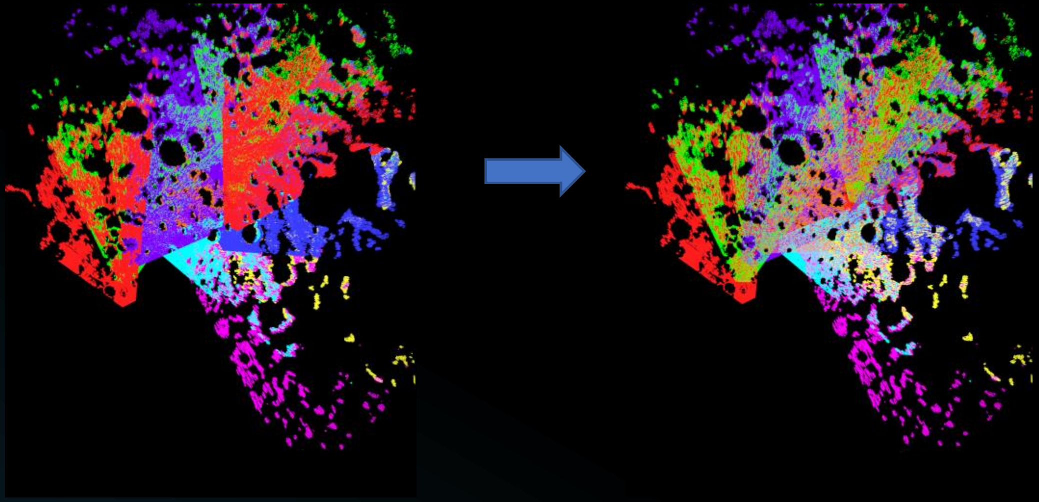
Relative pose estimation

- Visual odometry
- Input: stereo point clouds
- Consecutive single image pairs

Global pose estimation

- Terrain registration
- Matching stereo panoramas to orbital DEMs

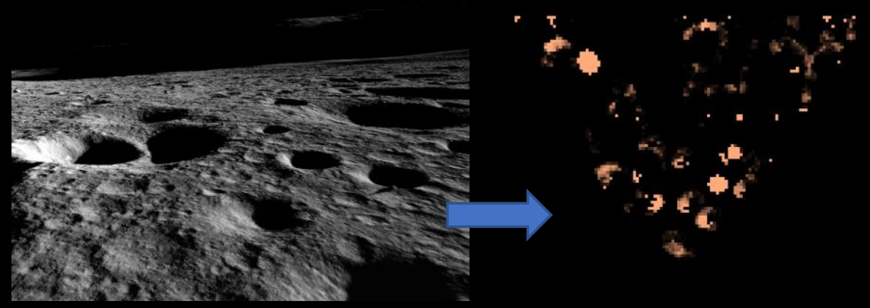




RGSW – Mapping and Path Planning

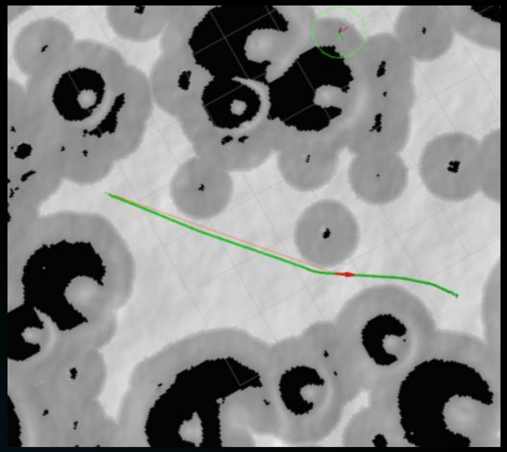
Mapping

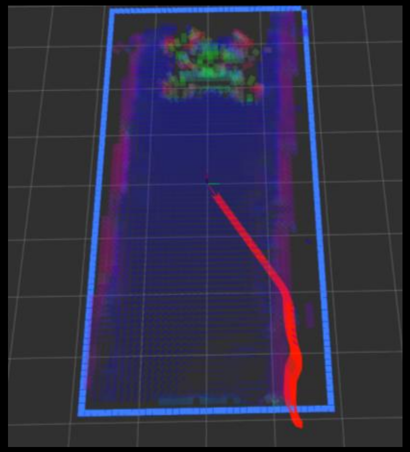
- Driver situational awareness
- Map generation from stereo point clouds
- Texture mapping to stereo point cloud
- Terrain hazard analysis (slopes, rocks & craters)



Path planning

- Path suggestions as human operator input
  - Advanced driver assist system (ADAS)
  - Terrain constraints vs pre-planned traverse path
- Motion prediction
  - No lateral/longitudinal on-board slip correction
  - Given terrain constraints and slip model
  - Predict most likely end-point of rover drive
  - Path of least surprise

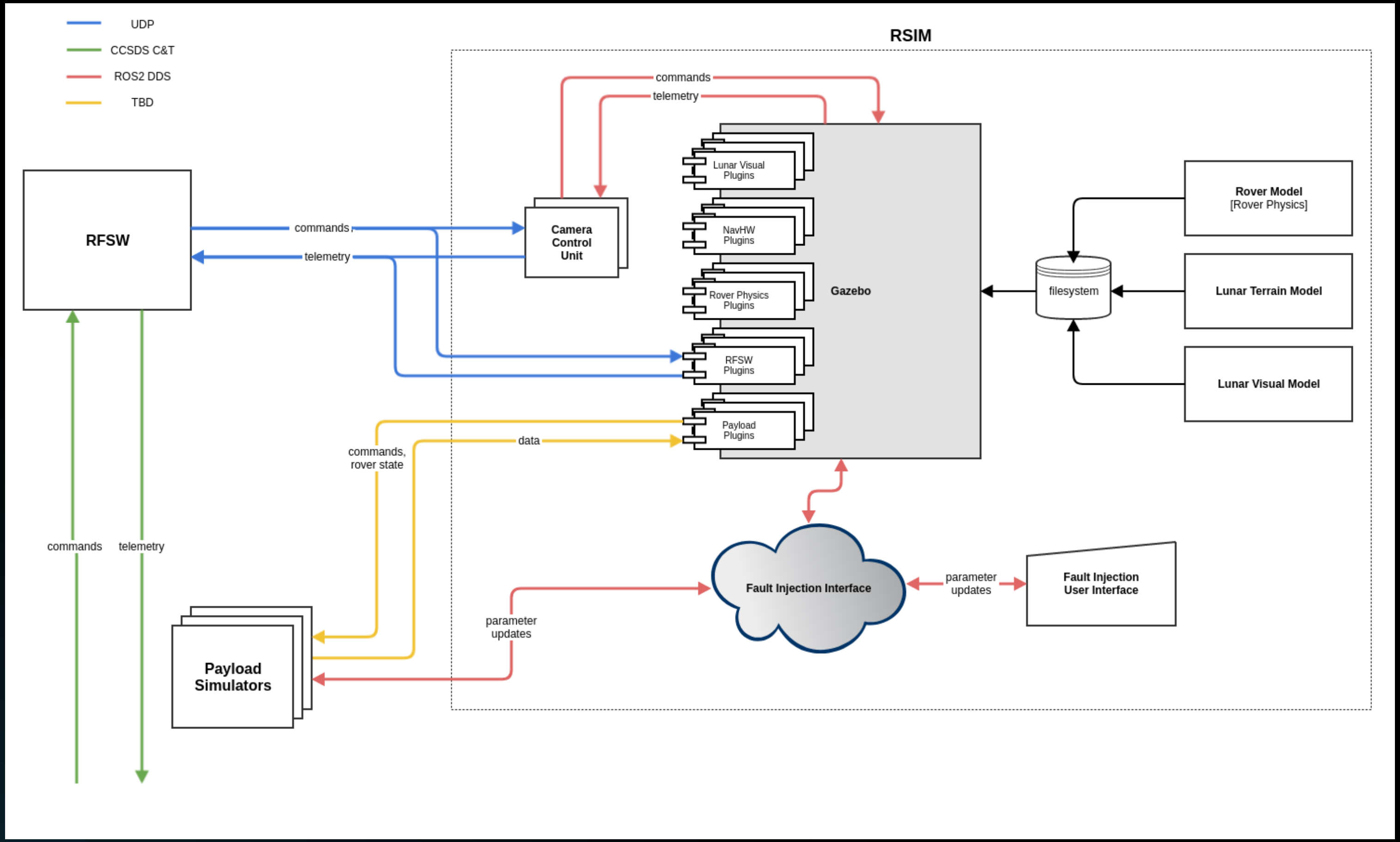




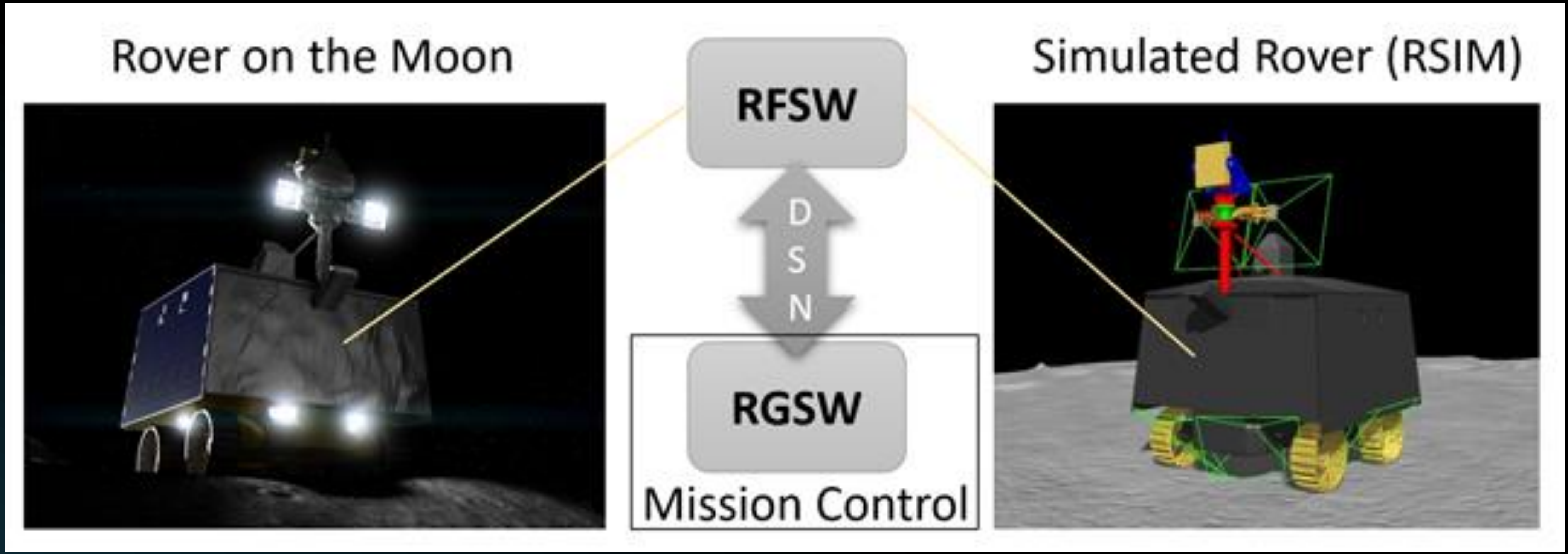
VIPER Rover Simulations (RSIM)

RSIM Architecture

- Gazebo based
- Ensemble of plugins
- Rover model
- Lunar terrain
- Lunar visual environment
- Rover sensors
- Rover actuators
- Fault injection



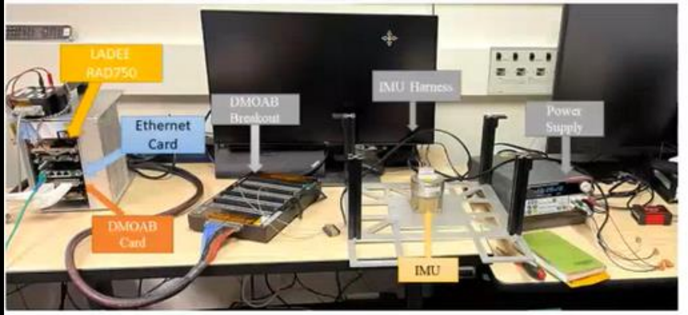
RSIM/RFSW Integration



- Devices modeled at the protocol level
- Connected via virtual serial ports/UDP (socat)

VIPER Rover Software Development

Software Test Platforms

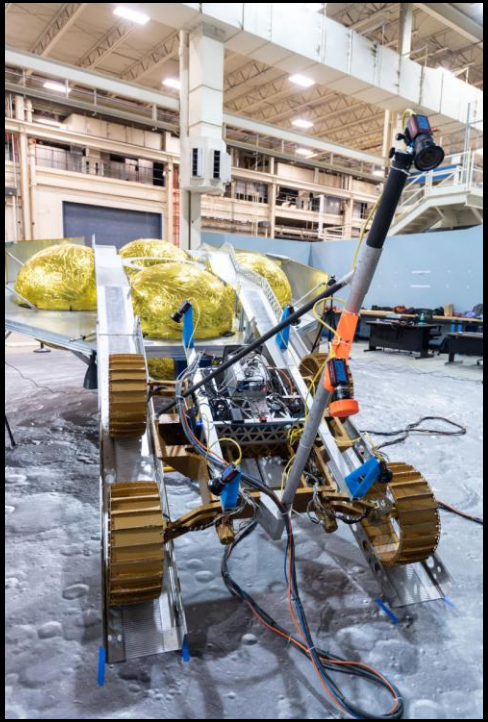


Supporting multiple platforms

- Different levels of fidelity
- Ease of access and tool support

Linux laptops and servers

- Familiar development environment for software team
- Immediate availability
- Advanced tools (valgrind, cachgrind…) for debugging and unit-testing



PPC Software Emulation (Qemu RAD750) with VxWorks

- Flight forward processor (big endian), memory, operating system, compiler toolchain
- Available on every developers laptop

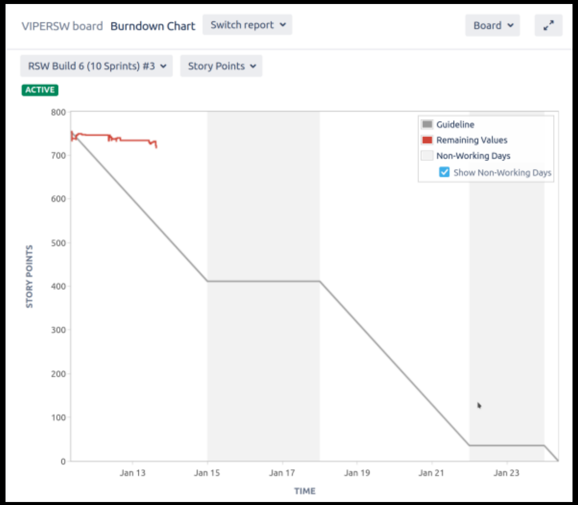
Software Development Units (SDU) from previous mission

- Early availability of similar processor and accessory cards
- Risk mitigation such as early performance measurements etc

Engineering Development Units

- Requirements verification

Agile Development and DevOps



VIPER as a mission follows waterfall model

Rover Software is implemented in 7 build cycles/releases

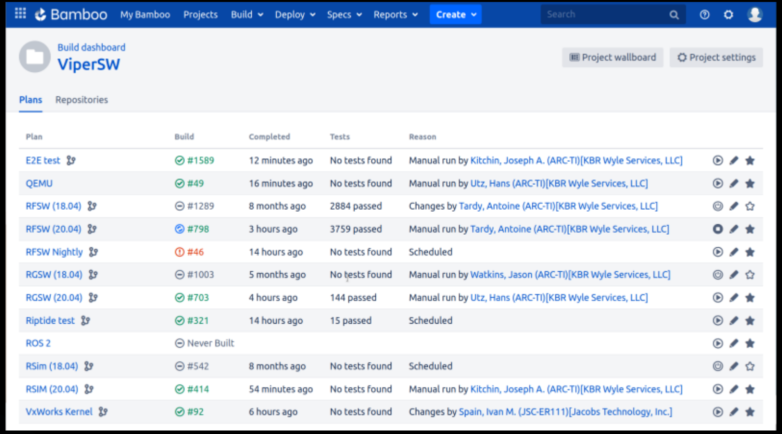
- Build spec defining the feature set
    - Build requirements
    - Software requirements
- Acceptance testing
- Integration and test phase with customers after release

Agile development within the build cycles

- 2 week sprints
- Concluding in project-open ShowAndTell

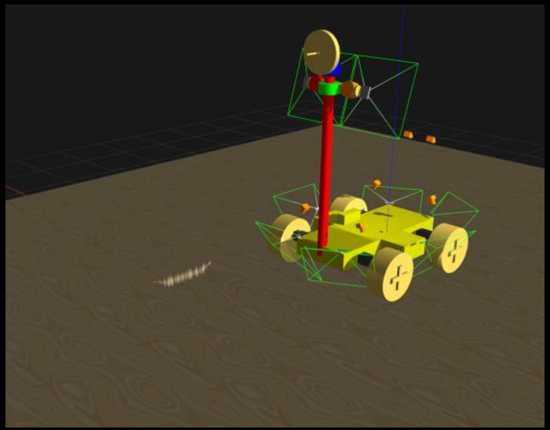
Development operations

- Continuous integration environment
- Building all sources on both supported platforms
- Running all automated tests: unit tests, subsystem test, end-to-end tests (RSIM)

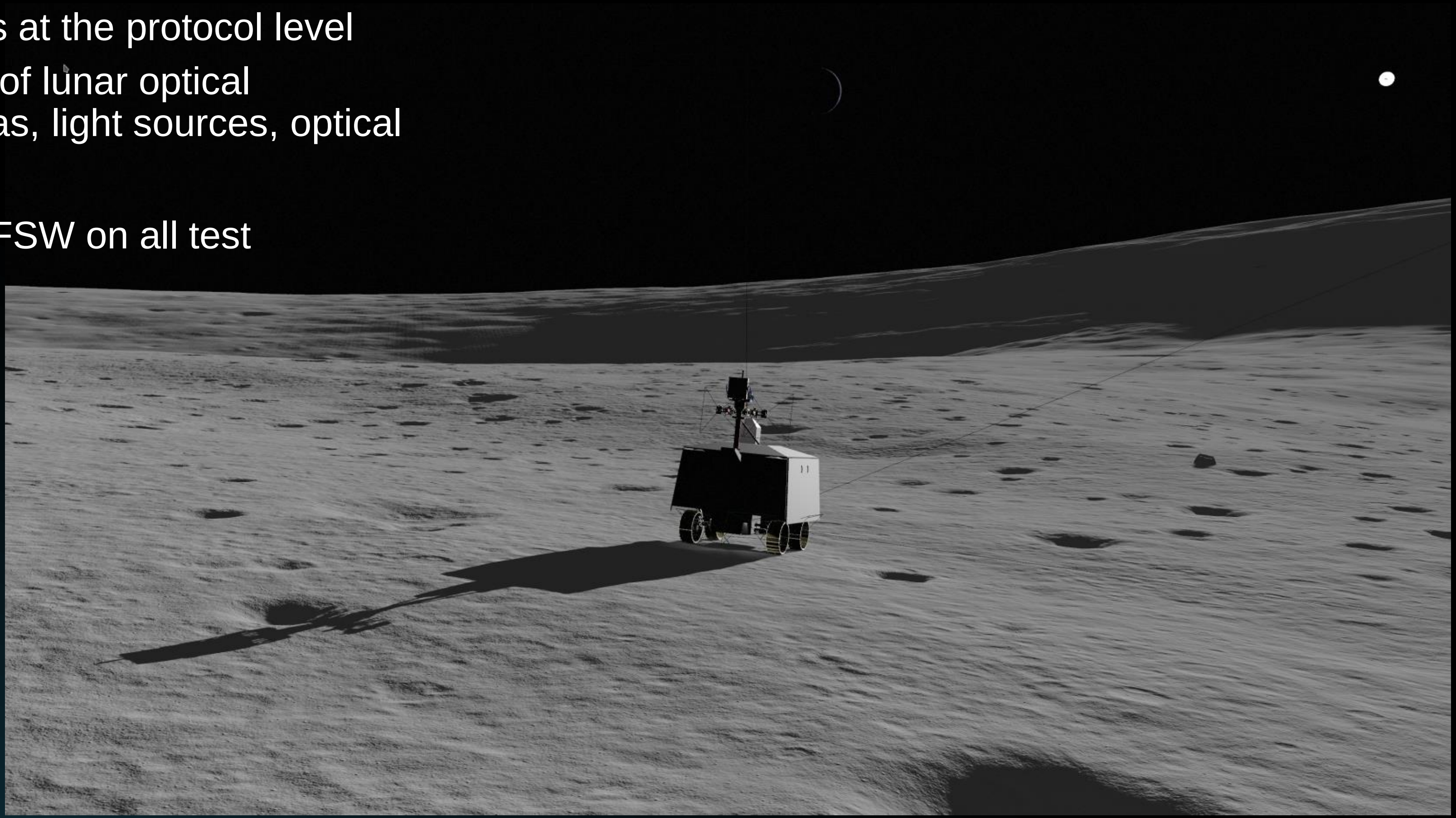


Plan	Build	Completed	Tests	Reason
E2E test	#1589	12 minutes ago	No tests found	Manual run by Kitchin, Joseph A. (ARC-TI)[KBR Wyle Services, LLC]
QEMU	#49	16 minutes ago	No tests found	Manual run by Utz, Hans (ARC-TI)[KBR Wyle Services, LLC]
RFSW (18.04)	#1289	8 months ago	2884 passed	Changes by Tardy, Antoine (ARC-TI)[KBR Wyle Services, LLC]
RFSW (20.04)	#798	3 hours ago	3759 passed	Manual run by Tardy, Antoine (ARC-TI)[KBR Wyle Services, LLC]
RFSW Nightly	#46	14 hours ago	No tests found	Scheduled
RGSW (18.04)	#1003	5 months ago	No tests found	Manual run by Watkins, Jason (ARC-TI)[KBR Wyle Services, LLC]
RGSW (20.04)	#703	4 hours ago	144 passed	Manual run by Utz, Hans (ARC-TI)[KBR Wyle Services, LLC]
Riptide test	#321	14 hours ago	15 passed	Scheduled
ROS 2	Never Built			
RSim (18.04)	#542	8 months ago	No tests found	Scheduled
RSIM (20.04)	#414	54 minutes ago	No tests found	Manual run by Kitchin, Joseph A. (ARC-TI)[KBR Wyle Services, LLC]
VxWorks Kernel	#92	6 hours ago	No tests found	Changes by Spain, Ivan M. (JSC-ER111)[Jacobs Technology, Inc.]

End to End Testing With RSIM



- RSIM as Rover Stand-in
  - Emulating all devices at the protocol level
  - Hi-fidelity simulation of lunar optical environment (cameras, light sources, optical surface properties)
- Running w/ unmodified RFSW on all test environments
- Chain including RSIM, RFSW, RGSW and ground tools such as YAMCS
- Python scripting of test procedures



https://www.youtube.com/watch?v=w-ylrw0zdqM

Status

- Build 6 of 7 started in December
- Feature complete with Build 6
- About 1 year from SW delivery
- Less than 2 years from launch (late 2023)

Questions?